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The NASA Lewis Research Center Water Tunnel Facility

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The NASA Lewis Research Center Water Tunnel Facility

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Summary

A water tunnel facility specifically designed to investigate internal fluid duct flows has been built at the NASA Research Center. It is built in a modular fashion so that a variety of internal flow test hardware can be installed in the facility with minimal facility reconfiguration. The facility and test hardware interfaces are discussed along with design constraints for future test hardware. The inlet chamber flow conditioning approach is also detailed. Instrumentation and data acquisition capabilities are discussed. The incoming flow quality has been documented for about one quarter of the current facility operating range. At that range, there is some scatter in the data in the turbulent boundary layer which approaches 10 percent of the duct radius leading to a uniform core.

Introduction

Current research efforts at NASA Lewis Research Center are focused towards a better understanding of the physics of internal duct flows that are encountered in aircraft engine applications. These include both engine inlet diffuser ducts and nozzle transition ducts.

Aircraft engine inlet diffuser ducts are used both for inlet flow diffusion and total pressure recovery as well as directing the inlet flow to the gas turbine compressor face. These diffusers tend to have complicated geometries which may lead to undesired flow distortion at the compressor face if not designed properly. In addition to cross-sectional area changes of the duct, there may be geometric changes where the duct cross section may transition from a square or rectangular at the inlet to a circular cross section at the exit. The flow physics may be further complicated by the addition of bends in the duct required by the engine-airframe integration process.

Current research interest in diffuser or nozzle transition ducts, whether in subsonic or supersonic flow fields, lean towards those that have a geometric cross-sectional change from square or rectangular to circular (at the duct exit). A more complete understanding of the complex, three-dimensional subsonic flow field within ducts is necessary in order to design ducts capable of meeting the performance requirements envisioned by future propulsion systems. Current experimental techniques used at NASA Lewis are limited to either visualization at the duct surface or flow field measurements at discrete cross-stream planes. An increased understanding of this complex flow field can be obtained by visualization of the entire flow field. To do this in air flows, smoke is commonly introduced into the flow to visualize streamlines; in water flows the injection of dye is favored.

Visualization in water is generally preferred to air because the mixing of dye filaments in water is less intense than the mixing of smoke filaments in air. Buoyancy effects are also less troublesome in water than air.

Small water tunnels have been constructed in the past at NASA Lewis. These facilities are used to visualize external flow; models are placed in the test section and the flow around the model is visualized. A water tunnel facility was constructed to study internal flows where the duct model is the test section. This facility will augment duct flow studies performed in the Internal Fluid Mechanics Facility in cell W-1B. The water tunnel facility is designed to accept models that are the same size as used in cell W-1B. When a duct model is fabricated for testing in W-1B a duplicate Plexiglas model could be fabricated to test in the water tunnel facility. In addition, other models may be installed in the test region where flow around the model can be visualized. The purpose of this paper is to describe this facility in detail.

Facility Description

A photograph of the Water Tunnel Facility is shown in figure 1, and a facility schematic is shown in figure 2. The overall length of the facility is approximately thirty feet, although this will vary to accommodate different duct models or to change the boundary thickness at the test section. Changes in the height of the exit chamber can also be made if the duct model centerline changes from inlet to exit. The facility consists of three main components: (1) the inlet chamber, (2) the test region, and (3) the exit chamber. A motor driven pump is

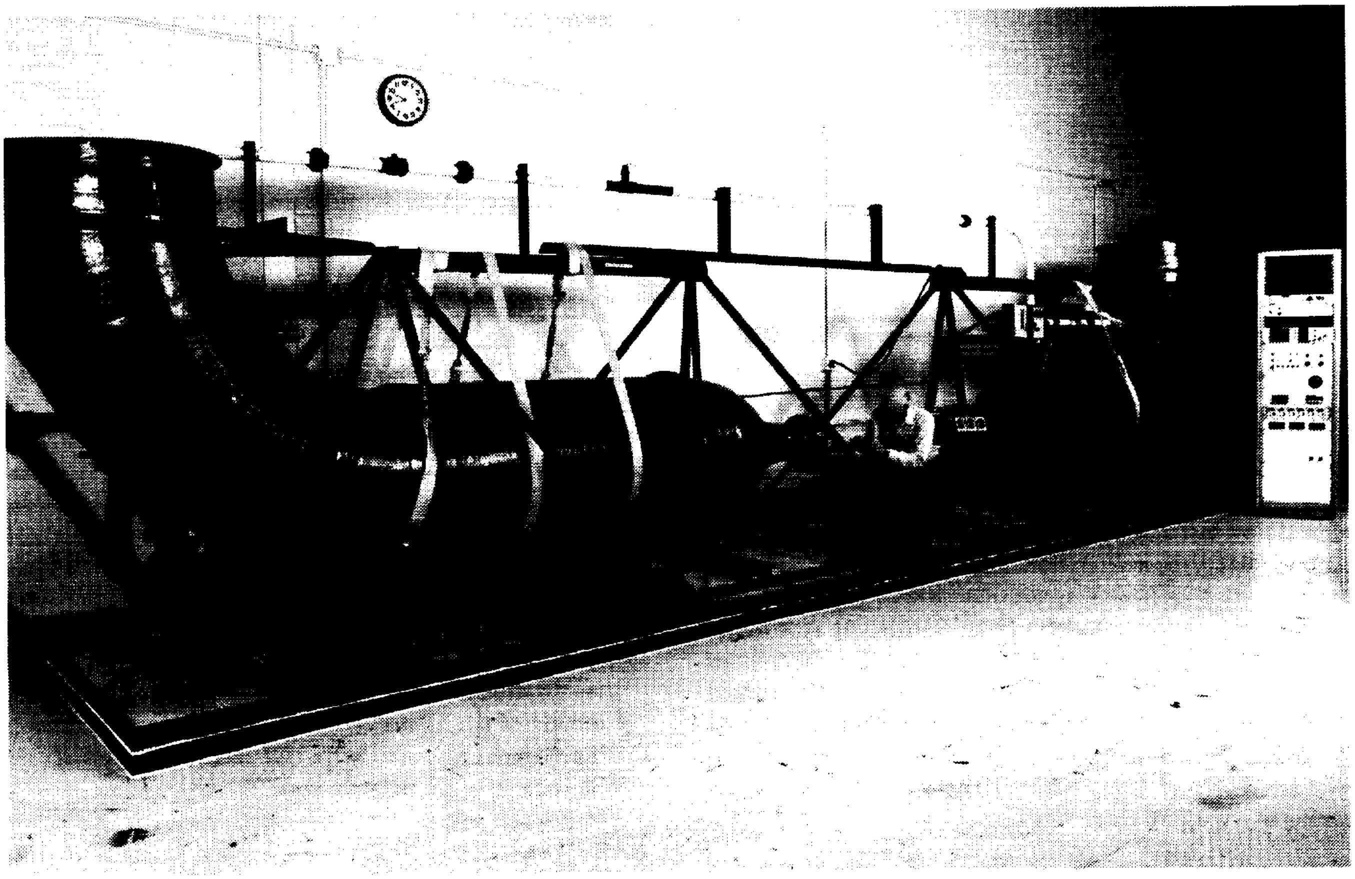

Figure 1.—Water tunnel facility.

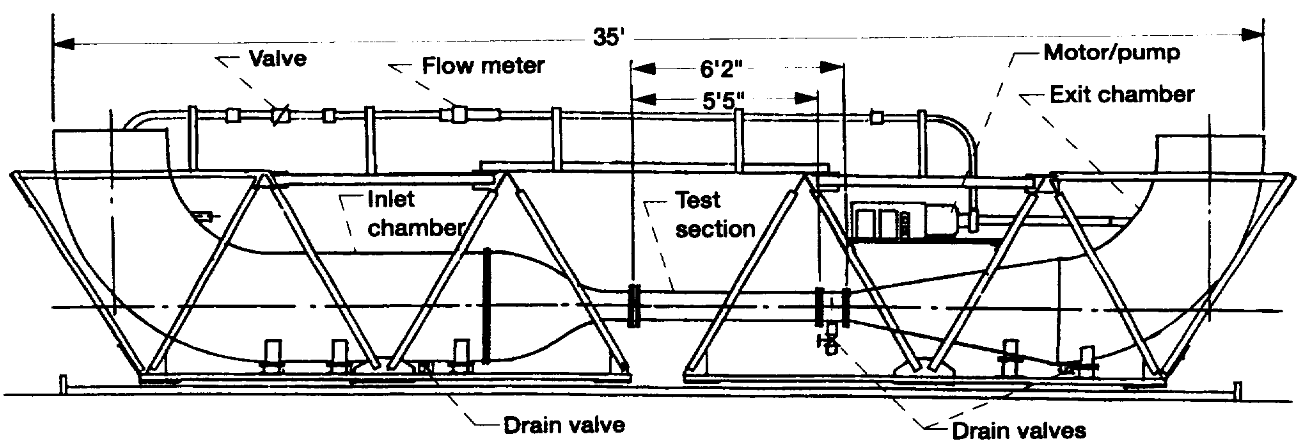

Figure 2.—Schematic of water tunnel facility.

located above the exit chamber. The pump inlet is connected to the exit chamber by a 2 in. pipe. Another 2 in. pipe connects the pump exit to the inlet chamber. This section of pipe contains a flow meter and a valve to vary the flow rate. Both ends of the tunnel are open to the atmosphere in the straight vertical sections above both elbows. A five horsepower electric motor drives the pump. The pump generates the pressure necessary to allow water to flow from the exit chamber to the inlet chamber of the facility. This setup provides a closed loop that gives this facility the capability to run continuously.

Inlet Chamber

The inlet chamber is used to diffuse and condition the incoming flow to the test region. It consists of a 3 ft diameter fiberglass reinforced plastic (FRP) pipe that translates from vertical to horizontal through an elbow as shown in figure 2. At the exit end of the horizontal pipe is a contraction section that attaches directly to the test region.

Water is pumped into the vertical end of the inlet chamber through the 2 in. pipe. This pumping into the upstream end causes swirling in the tunnel which can affect the flow in the test section. A strainer (plastic colander) was installed about a foot below the water line to diffuse the incoming flow. After the flow turns through the elbow, a honeycomb/screen combination is used to remove the small scale turbulence in the flow just before it enters a contraction section. This flow conditioning configuration is viewed as an unconventional arrangement compared to that suggested by Burley and Harrington (ref. 1).

The contraction section is used to transition the flow from the inlet chamber into the facility test region. The conical contraction section translates from a nominal 3 ft to the 8.04 in. diameter of the test region. The 8.04 in. diameter is the same as that used in cell W-1B (see Introduction). Appendix A discusses the inlet chamber and the contraction section aerodynamic components in detail.

Test Region

The next section of the water tunnel is the test region where the experimental hardware is installed. The test region consists of a transition flange, a test section and a drain section all made of Plexiglas. The transition flange was installed to make up the slight difference in diameters between the conical exit of the inlet chamber and the test section tube of the test region. The drain section was installed to drain water from the test region when a configuration change or other work needs to be done on the model. This test region is very versatile in the sense that any hardware can be installed in this region as long as proper interfaces are designed to mate the test hardware with the transition flange and the drain section. The present test section's allowable maximum length is 5 ft, 5 in. as shown in figure 2. Therefore, the experimental hardware must be designed to fit within this dimension.

Figure 3 shows a plexiglas transition duct that could be used in the water tunnel. Appropriate hardware would have to be made to connect this model to the drain section when this model is tested. Another example is shown in figure 4. In this case, the test region was modified by installing a pad where a test article, in this case a blade, was installed. The flow around the article could then be visualized. In the present case, a dye flowing through a hole in the tip of the blade was visualized, and is shown in figure 5. The center of the modification was made about 40 in. from the upstream end of the test region to allow a turbulent boundary layer to develop.

Exit Chamber

The exit chamber is the final section of the Water Tunnel Facility. Its primary function is to diffuse the flow from the test region and direct it to the pump. The exit chamber, as shown in figure 2, uses a conical section to connect the test region to the exit chamber. The conical section is connected to a nominal 3 ft diameter elbow; both are made of FRP material. The elbow translates from horizontal to vertical. A 2 in. diameter pipe is located about 2 1/2 ft from the top of the vertical section that is connected to the pump.

Test Conditions

The pump unit specified for the water tunnel has a capacity of approximately 150 gal/min (GPM) at the expected head loss associated with the tunnel, test section, and return leg. This will provide a maximum velocity of approximately 1.0 ft/s through an 8 in. diameter duct model. However, most tests are expected to be performed at slower velocities (0.25 to 0.5 ft/s) which give optimum visualization results. Flow velocities are set by the valve downstream of the pump.

Water Tunnel Conditioning

Water if left in the tunnel for any length of time tends to collect dirt and other contaminants. This results in a time consuming task of cleaning the entire tunnel after the water has been drained. In order to maintain the long term cleanliness of the tunnel, drains were installed in the bottom of both the downstream and upstream chambers of the tunnel which will drain the tunnel completely in a short period. When the tunnel is idle for a long period of time, it is drained so that no algae or bacteria buildup takes place. In addition, wooden lids are placed on top of the inlet and exit chambers to prevent debris from falling in.

It takes about 6 hr to fill the tunnel with deionized water. If the tunnel is drained to the bottom of the test section, it will take about 4 hr to refill the tunnel. If a hot film anemometer is used, the tunnel should sit for a period of time to let the gas settle out of the water and to let the water come to room temperature.

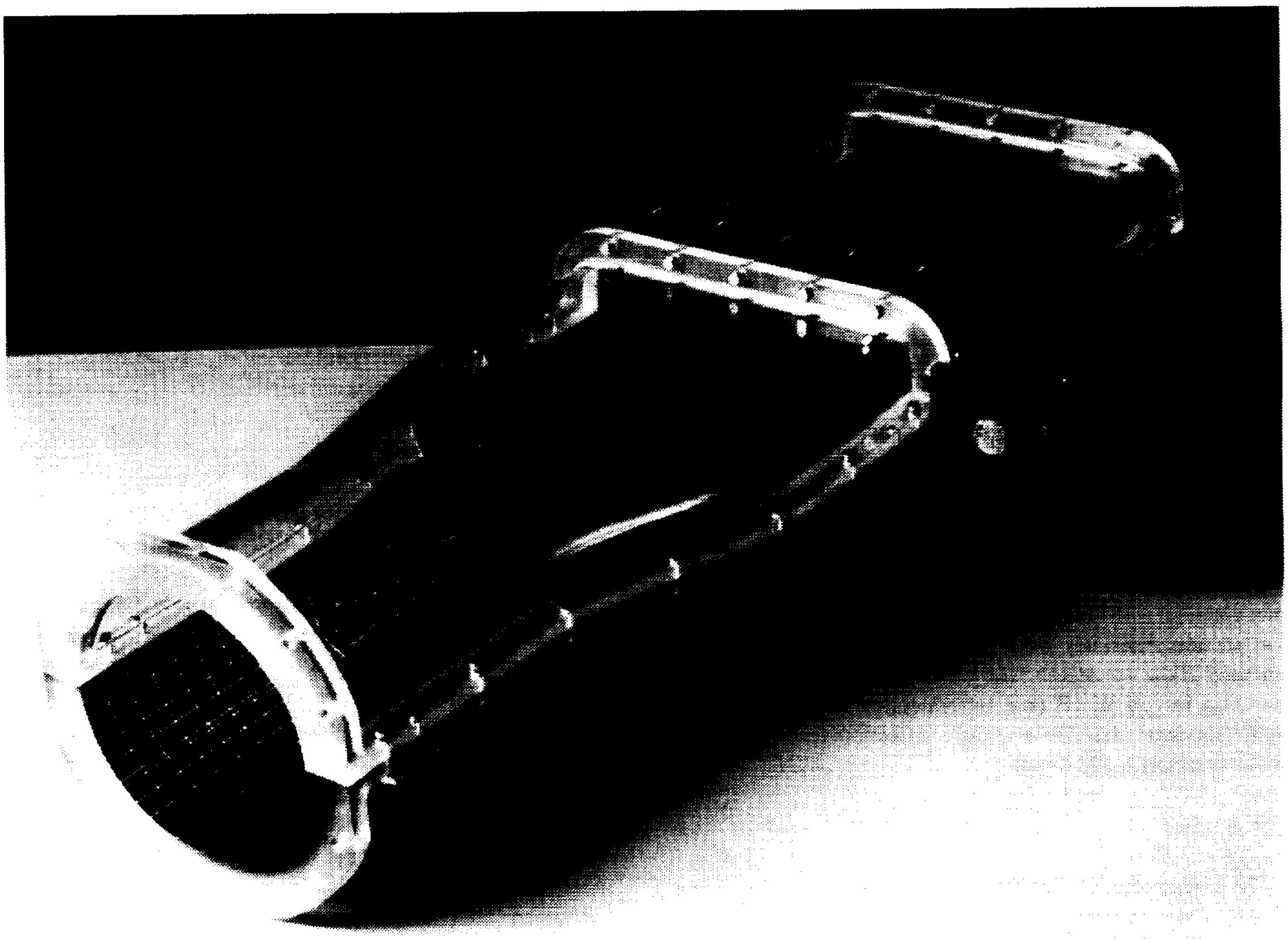

Figure 3.—Plexiglas transition duct diffuser.

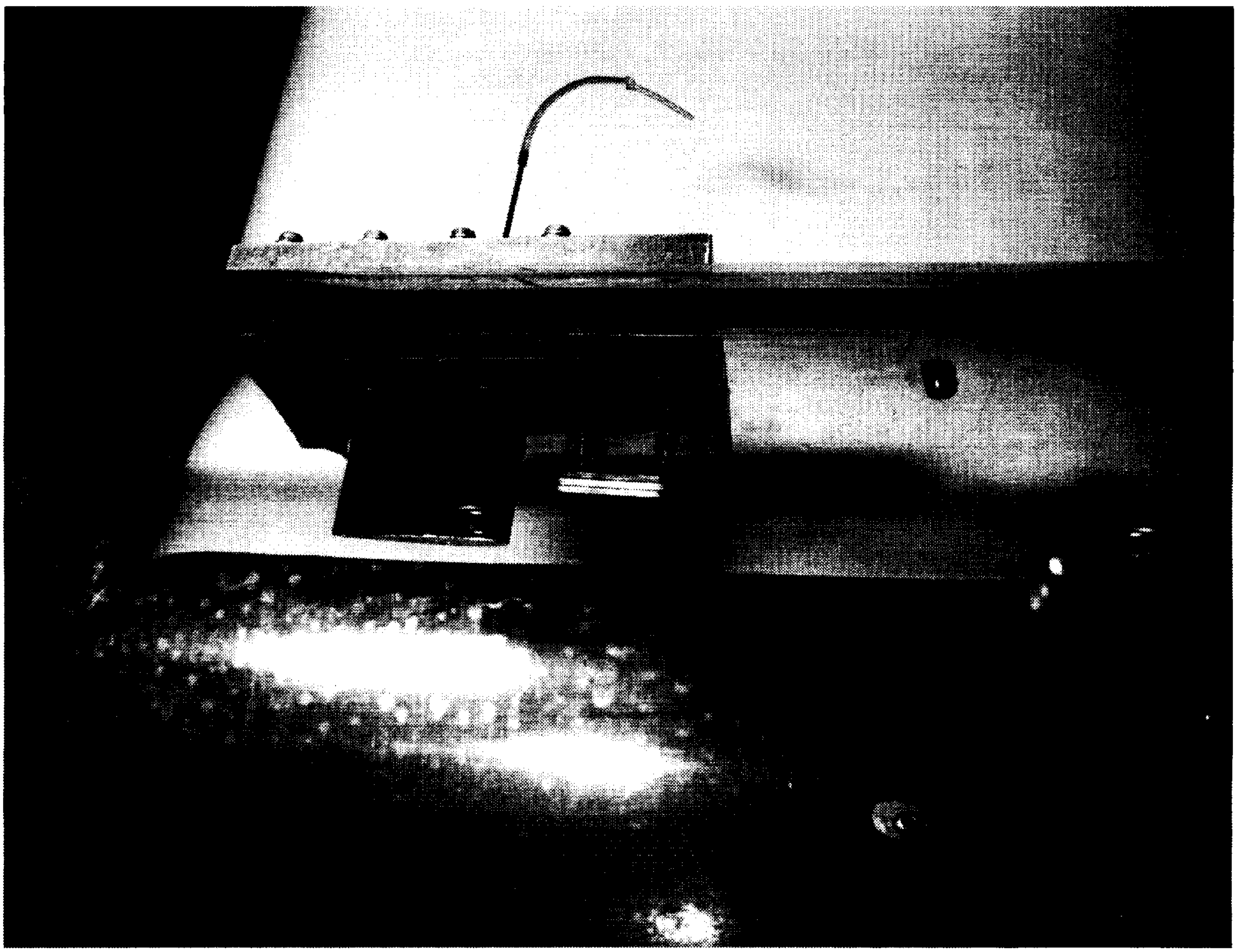

Figure 4.—Test section with blade specimen.

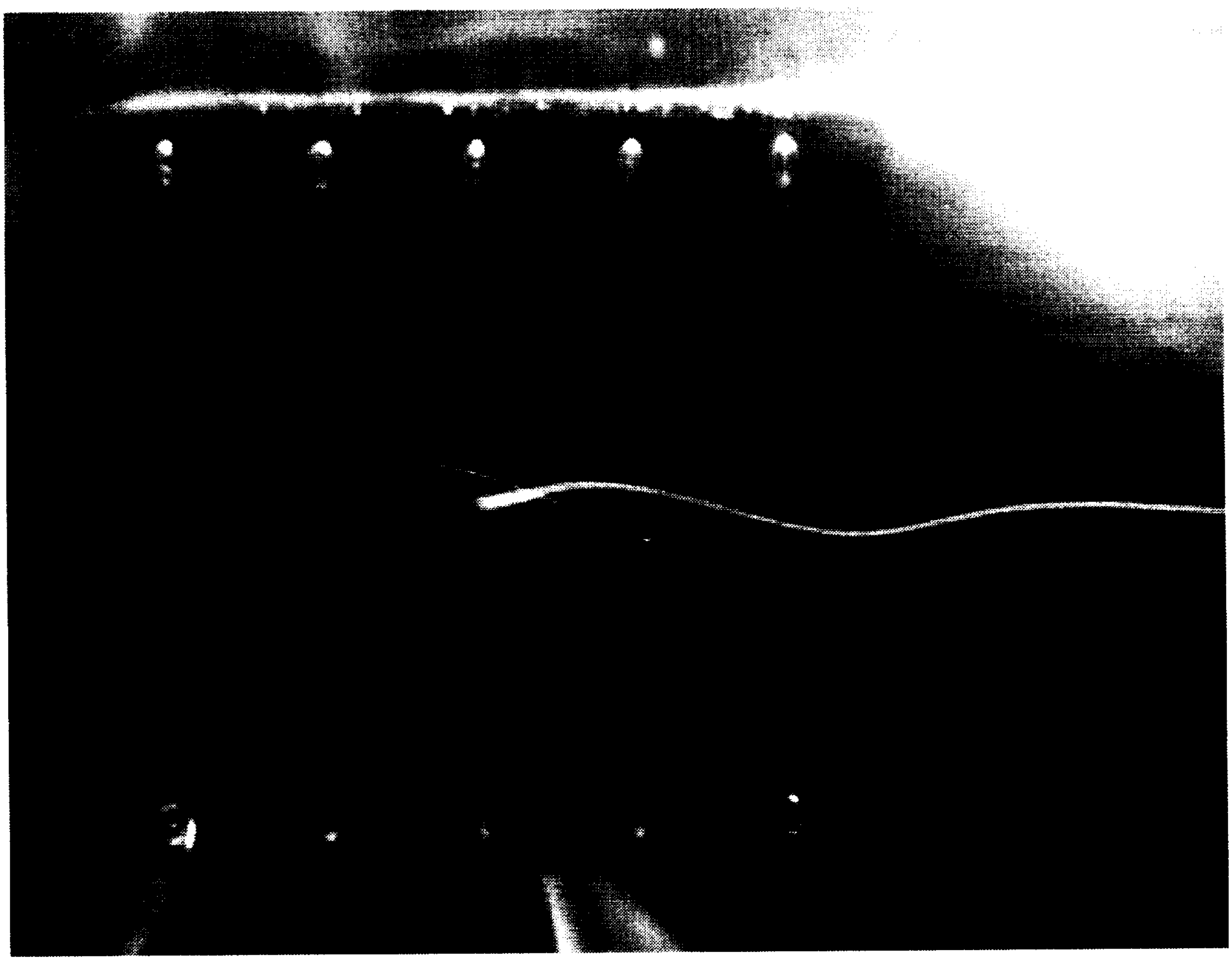

Figure 5.—Flow pattern at tip of blade specimen.

Instrumentation and Data Acquisition Capability

One method for generating flow visualization in a water tunnel is to use a hot wire in the flow upstream of the model. Heating the wire generates a series of small hydrogen bubbles along the length of the wire. These bubbles will reveal any vortices or wakes as they go around the model in one plane. Another method is to use a dye in the water. This has the advantage of viewing all the flow around the model. Since the objective is flow visualization, all data is acquired photographically with a 35mm camera or a video camera.

A hot-film anemometer can also be used. The hot film probe uses the existing probe fixture in the Plexiglas test section. The probe holder attaches to a stepper motor designed to control the motion of the probe in the test section (fig. 6). As the probe moves, its position is displayed on the stepper motor controls. The stepper motor is controlled by a Compumotor 3000 system (fig. 7). The anemometer is a IFA-100 model. The computer is a UNIX based system with FORTRAN compiled code controlling both the compumotor and the anemometer. The computer also acquires the data through an 8 bit A-D card. This computer system was used to calibrate the probe and the tunnel. This computer system can also be used with a video camera, as shown in figure 8.

Tunnel Flow Quality

The water tunnel calibration was done with a hot film probe anemometer. The hot film probe was calibrated in a water tank with deionized water. The hot film probe was then installed in the water tunnel and the tunnel was filled with deionized water.

The tunnel was turned on and the voltage output on the anemometer was observed. It takes approximately 15 min for the tunnel to achieve steady flow after it is turned on and after any velocity adjustment is made. The probe was moved back and forth in the center of the pipe diameter and the velocity varied by approximately 1 percent, (fig. 9).

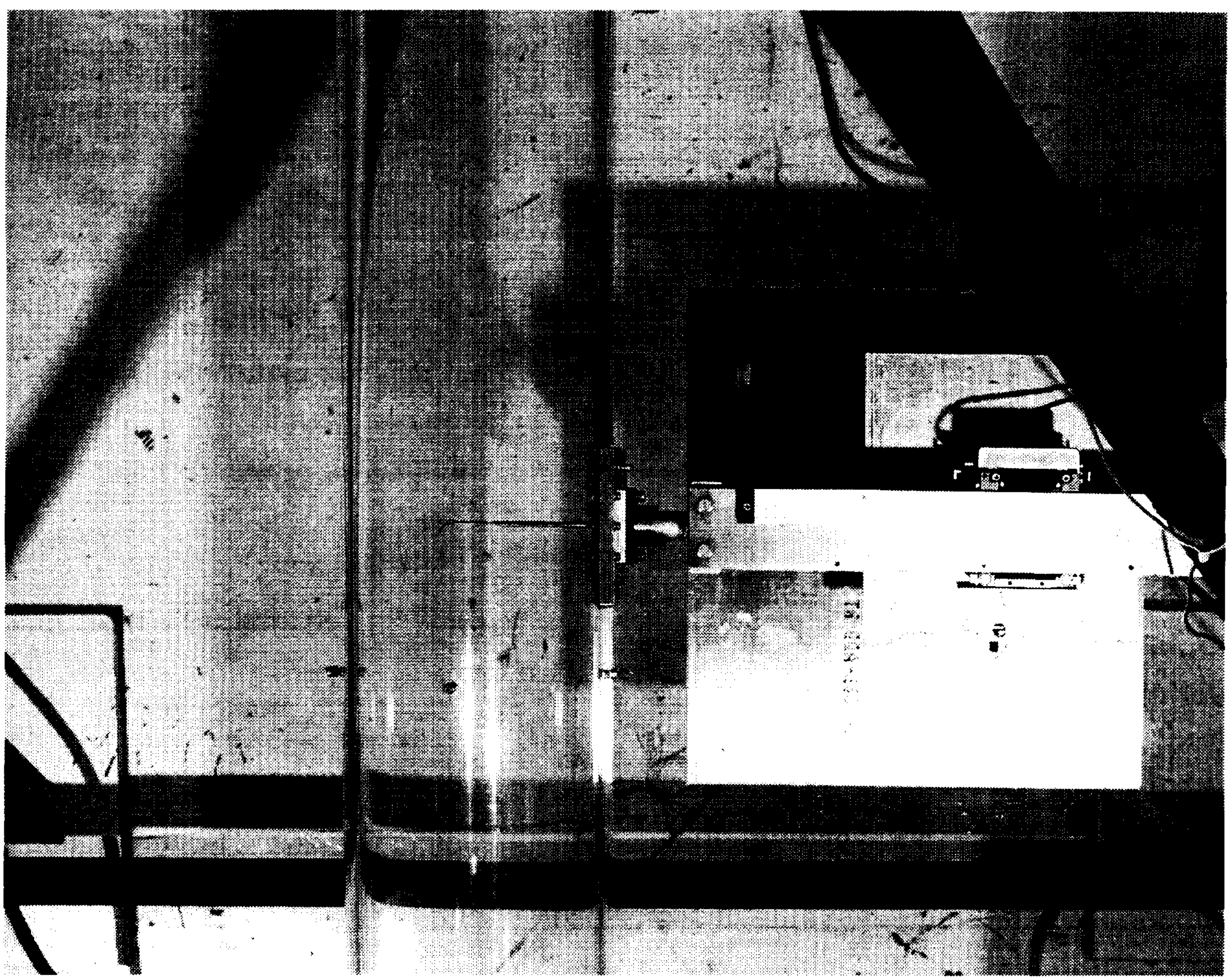

Figure 6.—Test section with anemometer probe.

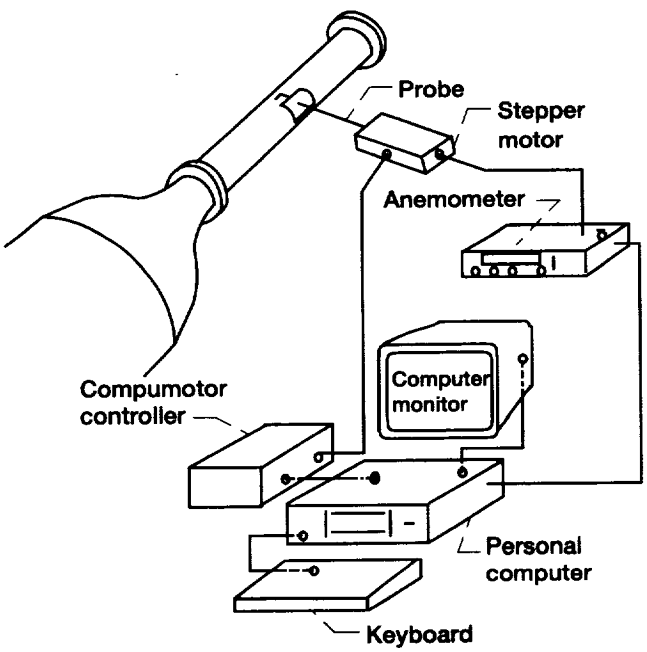

Figure 7.—Fluid flow tunnel calibration schematic.

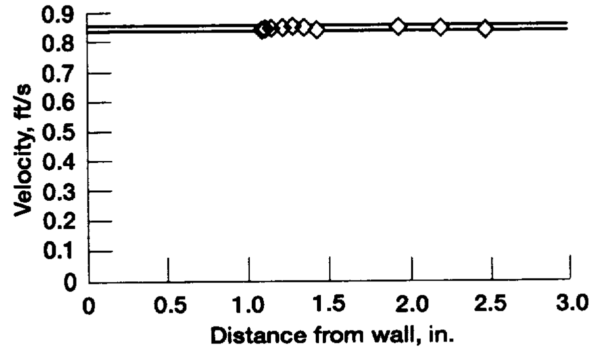

Figure 9.—Steady state velocity variation at 0.85 ft/s.

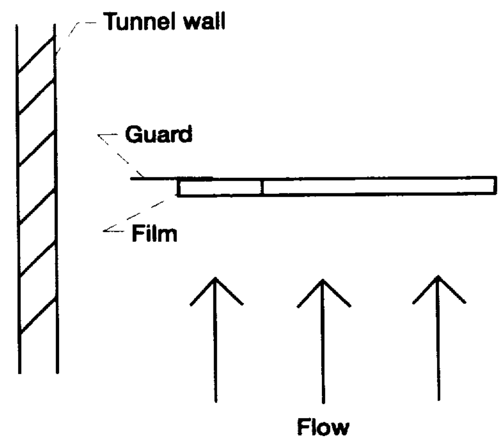

Figure 10.—Probe and tunnel wall schematic.

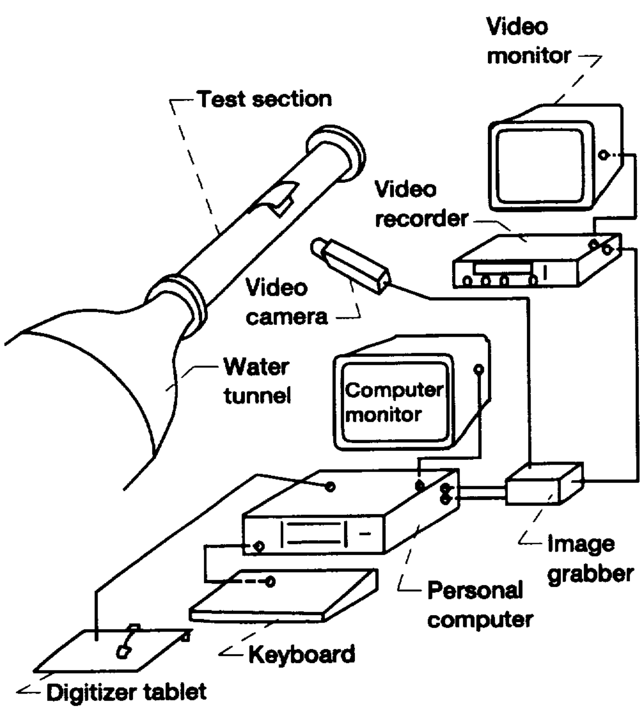

Figure 8.—Fluid flow digital imaging schematic.

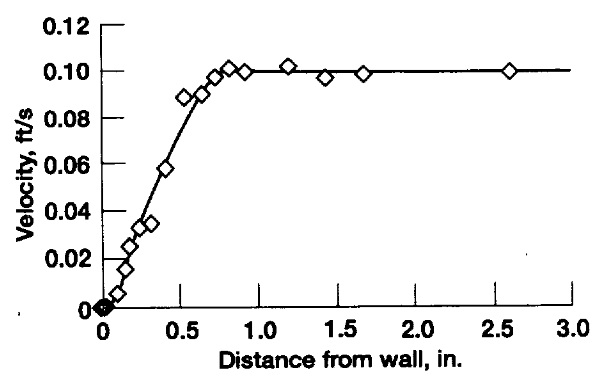

Figure 11.—Velocity distribution at 0.10 ft/s, Re = 6300.

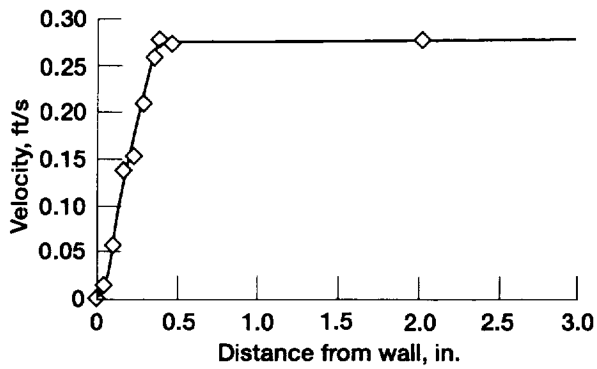

Figure 12.—Velocity distribution at 0.275 ft/s, Re = 19 000.

Next, the inside diameter of the tunnel was located. This was a difficult procedure, since the curvature of the Plexiglas tunnel distorted the view of the probe. The probe was moved in small increments toward the inside diameter of the tunnel each time examining the probe location and the anemometer voltage (fig. 10). When the guard on the probe visually contacted the wall, this was set as the outside diameter and all subsequent measurements were referenced to this value. The close proximity to the wall was reaffirmed by the voltage on the anemometer reading the equivalent of zero velocity.

Once the wall was referenced, the probe was moved away from the wall. The anemometer voltage and the position of the stepper motor was recorded at various locations.

Graphs of velocity vs. distance from the tunnel wall for two velocities tested are shown. Figure 11 shows core velocities at 0.1 ft/s with a boundary layer about 20 percent of the duct radius. Readings within the boundary layer were very unsteady when compared to the stable voltages toward the center of the test section. Figure 12 shows core velocities at 0.275 ft/s with a boundary layer about 10 percent of the duct radius. There seems to be much less scatter in the boundary layer readings at this higher velocity setting. Time and budget constraints did not allow tunnel calibration at higher velocities to be completed. These calibrations will be completed at a future date.

Concluding Remarks

A water tunnel facility specifically designed to investigate internal fluid duct flows has been built at the NASA Lewis Research Center. It was built in a modular fashion so that a variety of internal flow test hardware can be installed in the facility with minimal facility reconfiguration. The facility and test hardware interfaces are discussed along with design constraints for future test hardware. The inlet chamber flow conditioning approach is also detailed. Instrumentation and data acquisition capabilities are discussed. The incoming flow quality has been documented for about one quarter of the current facility operating range. At that range, there is some scatter in the data in the turbulent boundary layer which approaches 10 percent of the duct radius leading to a uniform core.

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Appendix A

Aerodynamic design of Facility Flow Conditioning

A schematic of the flow conditioning configuration installed in the inlet chamber of the water tunnel is shown in figure 13. The flow conditioners can be divided into three categories: (1) the strainer (plastic colander), (2) the honeycomb and screen, and (3) the contraction section.

The incoming water flow from the 2 in. diameter pipe creates a vortex in the flow and, therefore, has to be treated. A strainer (plastic colander) was installed about 1 ft. below the water line to diffuse the flow at this point.

The next set of flow conditioners are the honeycomb and screen, which are used to reduce the transverse components of turbulence, while the fine mesh screen reduces the axial turbulence levels. The conventional flow conditioning techniques, that were investigated by Burley and Harrington (ref. 1), typically use a series of fine mesh screens spaced a discrete distance apart, and sometimes these screens are preceded by a honeycomb assembly. The configuration used for this facility is viewed as an unconventional arrangement because it uses only a honeycomb/single fine mesh screen assembly. Both are located about 2 ft upstream of the exit flange.

Although this configuration was not the best in reducing turbulence, it was chosen because of two important factors. The first factor is ease of installation. In the conventional configuration, isolated fine mesh screens are spaced a discrete distance apart which requires an elaborate tensioning and mounting assembly to be fabricated for the screens. These assemblies tend to be quite costly and often are difficult to integrate into an existing design. Also, since the length of the inlet section is short, it does not allow room for multiscreen assembly. In the case of the configuration chosen for this facility, the single fine mesh screen is attached directly to the honeycomb structure which eliminates the need for additional structural support devices and screen tensioning hardware.

The design criteria to be considered in order to integrate the flow conditioners are (1) the ratio of the honeycomb cell length dimension(L) to cell size dimension (D), (2) the ratio of the fine screen mesh size to the honeycomb mesh size and (3) the open area of the fine mesh screen.

In the conventional configuration suggested by Burley and Harrington, the L/D ratio must fall between 6 and 12, and the ratio of the fine screen mesh size to the honeycomb mesh size must be between 3 and 4, and the fine mesh screen requires an open area of at least 60 percent.

The configuration used for this facility is viewed as an unconventional arrangement because it does not follow the design criteria used in a conventional configuration. The honeycomb chosen for this water tunnel has a hexagonal-shaped cell cross-section. The cell size dimension is defined as the distance between two opposing flats of the hexagon. The effective mesh spacing for the honeycomb can also be defined

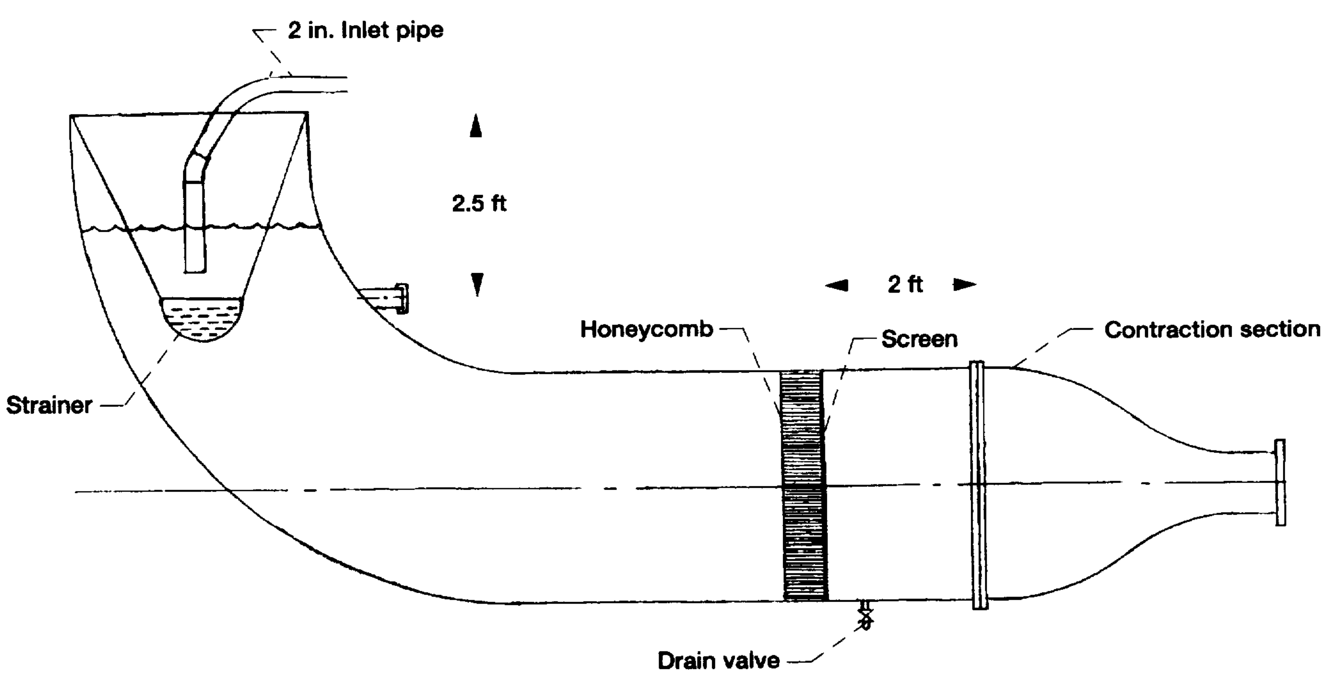

Figure 13.—Inlet chamber schematic.

as the number of these flats parallel to each other in a one inch span. The cell size is 1/4 in., and the cell length is 6 in. The screen has a 24/in. mesh with a 76 percent open area.

Taking the design criteria into consideration, the L/D ratio for the honeycomb is 24. Since the effective honeycomb mesh size is 4, the screen mesh to honeycomb mesh ratio is 6. Except for the open area of the fine mesh screen, all of these results are out of the design limits suggested by Burley and Harrington.

The second factor to consider is the flow conditioning approach as a whole. In addition to using the screen and honeycomb to reduce turbulence, The contraction section will also aid in the turbulence reduction process. The contraction section geometry was generated by a cubic spline fit to provide smooth accelerated flow with no flow separation. The total length of the contraction section is approximately 48 in. The upstream diameter of the contraction section is 36.00 in. and the downstream diameter is 8.04 in. This gives an area ratio of 21. Although the contraction section area is not large , it produces a uniform flow field in the test section's boundary layer duct with the boundary layers approximately 10 percent of the duct radius in the range of flow velocities to be used in the water tunnel(i.e., 0.25 to 0.50 ft/sec). This satisfied the flow conditioning for the water tunnel without incurring the additional costs of using a more elaborate honeycomb and multiple screen flow conditioning design.

Reference

1. Burley, R.R.; and Harrington, D.E.: Experimental Evaluation of Honeycomb/Screen Configurations and Short Contraction Section for NASA Lewis Research Center's Altitude Wind Tunnel. NASA TP–2692,1987.

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13. ABSTRACT ***(Maximum 200 words)***

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